

Effect of different drying methods on drying characteristics, colour, total phenolic content and antioxidant activity of sliced green table olives

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RESEARCH ARTICLE

Abstract

This study analysed the effects of convective (50 and 75 °C), microwave (90 and 160 W) and combined microwave-convective (90 W-50 °C, 90 W-75 °C, 160 W-50 °C and 160 W-75 °C) drying methods on the drying characteristics, colour, total phenolic content and antioxidant activity of sliced green table olives. The shortest drying time was found with the combined microwave-convective 160 W-75 °C method, and it was found that the combined microwave-convective method provided the greatest time savings in comparison to other methods tested. According to the test results, the drying rate of samples increased with increasing convective temperature and microwave power. Based on the statistical tests used for evaluation, the Midilli *et al.* model was found to be the best model to explain test data for sliced green olives samples under all drying conditions. While the colour values L*, b*, and chroma and hue angle decreased, the colour value a* increased in dried sliced green olive samples. It was found that the 160 W microwave method gave colour values closest to those of fresh samples. Among the different drying treatments, the values to closest those of fresh green olive samples with respect to total phenolic content and antioxidant activity were achieved with the 160 W-75 °C combined microwave-convective drying method.

Keywords: food quality, microwave drying, mathematical model, drying rate, antioxidant activity

1. Introduction

The Mediterranean diet is associated with a long and healthy life; olives and olive oil are key parts of this diet, as they contain healthy compounds with positive effects on human health (Boskou *et al.*, 2006; Charoenprasert and Mitchell, 2012). Fatty acids (particularly monounsaturated) (Sakouhi *et al.*, 2011) and phenolic compounds play a significant part in the health benefits of olives and olive products (Kastorini *et al.*, 2010). Table olives are a rich source of antioxidants from natural phenolic compounds and are referred to as a functional food (Marsilio *et al.*, 2001).

The increasing focus of consumers on healthy diets and natural foods in recent years has led to the increased consumption of olives and the development of alternative olive products and processing methods (Kastorini *et al.*, 2010; Ryan *et al.*, 2002). Dried olives are one of these alternative products and are added to various mixtures

directly or after rehydration. They have potential uses in pizza, salads, garnishes and various sauces, particularly in Mediterranean cuisine. The use of dried olives has gradually increased due to long their shelf life, lower weight and volume during transport and ease of use in food preparation (Erbay *et al.*, 2010; Ongen *et al.*, 2005). The purpose of drying is to remove free water in fresh products, to increase the storage time of food and to stop or reduce biochemical reactions and the development of microorganisms. Various methods are used to dry food (Ruiz-López *et al.*, 2008; Tello-Ireland *et al.*, 2011). Convective drying is the most commonly used method in the food industry because of the low costs of initial investment and operation and the ease of controlling the process (Hiranvarachat *et al.*, 2011; Mundada *et al.*, 2010). However, the long drying period and high temperature and velocity of the drying air can damage the taste and biological components of food and have an adverse effect on the quality of the food (Maskan, 2001; Zhang *et al.*, 2006). The microwave drying is an alternative

drying method that significantly shortens the drying period without damaging food quality and that consumes less energy (Maskan, 2000). However, this method also comes with problems, such as unsteady heating, potential textural damage and high initial investment costs (Zhang *et al.*, 2006). In recent years, different drying methods have been used in combination to reduce these problems, to reduce loss of quality during drying and to increase energy efficiency (Contreras *et al.*, 2008). There has been a recent increase in studies using combined microwave drying and convective drying, hot air spray, vacuum and drying by freezing methods (Karaaslan and Tuncer, 2008; Sharma and Prasad, 2004; Sharma *et al.*, 2009).

This study aims to determine the drying characteristics of sliced green olives; select the best thin layer drying model among convective, microwave and combined microwave-convective drying methods; determine the effects of these drying methods on the colour, total phenolic content and antioxidant activity of olive samples; and identify quality parameters.

2. Materials and methods

Drying equipment and drying procedure

This study used samples of sliced green table olives in brine (outer diameter: 18.476 ± 1.005 mm; thickness: 5.426 ± 0.239 mm) supplied by Tadal (Bursa, Turkey) that produces brined olives commercially. The test materials were stored at 5°C until the end of tests (Vega-Gálvez *et al.*, 2010). The initial moisture content of the samples was determined as 3.82 g water/g dry matter on a dry basis (d.b.) by oven (ED115; Binder, Tuttlingen, Germany) drying at $105 \pm 5^\circ\text{C}$ for 24 h (Erbay *et al.*, 2010).

A laboratory microwave-convective oven (Whirlpool AMW 545; Whirlpool, Comerio, Italy) that operates at ~ 230 V,

50 Hz and a frequency of 2,450 MHz was used for the drying experiments. The system was operated in convective mode at an air velocity of 1 m/s with air temperatures of 50 and 75°C ; in microwave mode at output power levels of 90 and 160 W; and in microwave-convective mode at different power level and temperature combinations of 90 W- 50°C , 90 W- 75°C , 160 W- 50°C and 160 W- 75°C . All drying experiments were performed on a rotating glass plate with a 400 mm diameter at the base of the oven, which was $210 \times 450 \times 420$ mm in size. For each treatment, 200 g samples of olives were placed on a glass plate in a thin layer; they were dried to a final moisture content of 5% (d.b.) (Demir *et al.* 2007). For mass determination, a digital balance (Baster, Istanbul, Turkey) with ± 0.01 g accuracy was placed under the oven (Giri and Prasad, 2007). Moisture losses of samples were recorded in 5 min intervals during drying. Three replicates were performed for each sample, and the mean value was calculated.

Mathematical modelling of drying data

The moisture loss data were fit to nine models that are typically used to model drying curves (Table 1). The moisture ratio (MR) and drying rates of the olive samples during the drying experiments were calculated as follows (Özbek and Dadalı, 2007; Therdtai and Zhou, 2009):

$$\text{MR} = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

$$\text{drying rate} = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

Where M_t is the moisture content at a specific time (g water/g dry matter), M_0 is the initial moisture content (g water/g dry matter), M_e is the equilibrium moisture content (g water/g dry matter), M_{t+dt} is the moisture content at $t+dt$ (g water/g dry matter), and t is the drying time (min).

Table 1. Selected thin-layer mathematical drying models used for drying olives.

Model no.	Model name	Model	References
1	Henderson and Pabis	$\text{MR} = a \exp(-kt)$	Westerman <i>et al.</i> (1973)
2	Newton	$\text{MR} = \exp(-kt)$	Ayensu (1997)
3	Page	$\text{MR} = \exp(-kt^n)$	Agrawal and Singh (1977)
4	Logarithmic	$\text{MR} = a \exp(-kt) + c$	Yagcioglu <i>et al.</i> (1999)
5	Two Term	$\text{MR} = a \exp(-k_0t) + b \exp(-k_1t)$	Madamba <i>et al.</i> (1996)
6	Two Term Exponential	$\text{MR} = a \exp(-kt) + (1-a) \exp(-kat)$	Sharaf-Eldeen <i>et al.</i> (1980)
7	Wang and Singh	$\text{MR} = 1 + at + bt^2$	Wang and Singh (1978)
8	Diffusion Approach	$\text{MR} = a \exp(-kt) + (10a) \exp(-kbt)$	Kassem (1998)
9	Midilli <i>et al.</i>	$\text{MR} = a \exp(-kt^n) + bt$	Midilli <i>et al.</i> (2002)

MR = moisture ratio.

Colour measurement

The colour of fresh and dried olive samples was determined on the external surface of the samples using a Hunterlab Colour Analyzer (MSEZ-4500L; Hunterlab, Reston, VA, USA) in the L, a, b colour scale. Colour measurements were expressed in a three-dimensional L*, a*, and b* colour space, where L* represents the darkness/lightness of the sample, a* represents the redness (positive) and greenness (negative), and b* represents the yellowness (positive) and blueness (negative) (Reddy, 2006). After the colorimeter was calibrated against a standard white and black surface, six replicate measurements were performed for each sample. A cell with a diameter the size of the nose cone of the colorimeter containing the sample was placed above the light source, and the L*, a* and b* colour values were recorded (Odjo *et al.*, 2012). To describe the colour changes, chroma (C) and hue angle (α) values were calculated using the a* and b* parameters as defined by the following equations (Soysal, 2004):

$$C = \sqrt{(a^*)^2 + (b^*)^2} \quad (3)$$

$$\alpha = \tan^{-1} (b^* / a^*) \quad (4)$$

The saturation index, C value, is a good indicator of the amount of colour. The α value has the most significant correlation with visual scores. An angle of 0° or 360° represents a red hue, while angles of 90°, 180° and 270° represent yellow, green and blue hues, respectively (Karaaslan and Tuncer, 2008).

Preparation of sample extracts

Extracts of fresh and dried olive samples were prepared based on the method described by Turkmen *et al.* (2005). A sample of 1 g was extracted from each of the olive samples with 4.5 ml of 80% aqueous methanol using a mechanical shaker (Biosan OS-20; Biosan Ltd., Riga, Latvia) at 140 rpm for 2 h at room temperature. The extract was centrifuged at 10,000×g at room temperature for 15 min (Sigma 3K30; Sigma Laborzentrifugen GmbH, Osterode am Harz, Germany). The collected supernatant was then filtered through Whatman no. 1 (Whatman International Ltd., Maidstone, UK) filter paper and transferred to falcon tubes. The residue was re-extracted with 4.5 ml of 80% aqueous methanol and filtered. The supernatants obtained were combined to determine the total phenolic content and antioxidant activity of olive samples.

Determination of total phenolic content

Analysis of total phenolic content was conducted using the Folin-Ciocalteu method, similar to Singh *et al.* (2002). Three replicates of the analysis were conducted. A sample of 0.3 ml of methanolic extracts diluted at a 1/10 ratio

was added to 1.5 ml Folin-Ciocalteu reagent diluted at a 1/10 ratio, followed by the addition of 1.2 ml 1 mol/kg sodium carbonate; the mixture was incubated for 90 min. Absorbance values of samples were spectrophotometrically (Optizen 3220 UV; Mecasys, Daejeon, Korea) measured at 765 nm. The results were evaluated using a caffeic acid (CA) calibration curve and are presented in mg CA /100 g of olive on d.b.

Determination of antioxidant activity

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging method was used to evaluate the antioxidant activity of the olive extracts as described by Boskou *et al.* (2006) with minor modifications. The DPPH radical scavenging assay is based on the reduction of DPPH radicals in methanol solution, which causes an absorbance (A) drop at 515 nm. A 1 ml sample of each of the methanolic extracts of olive slices (prepared at 3 mg/ml concentration) was added to 3 ml of a 6×10⁻⁵ mol/kg methanolic solution of DPPH radical. The mixture was then vortexed for 15 to 30 sec and stored in the dark at room temperature for 60 min. After the incubation period, the discolouration of DPPH was measured against a blank in Optizen 3220 UV spectrophotometer (Mecasys). The samples were analysed in triplicate. The antioxidant activity of fresh and dried samples was expressed as percentage DPPH scavenging activity relative to the control and was calculated using the following equation:

$$\text{DPPH scavenging activity\%} = \frac{(A_{\text{control}} - A_{\text{sample}})}{A_{\text{control}}} \times 100 \quad (5)$$

Statistical analysis

This research was conducted using a randomised plot factorial experimental design. Determination of the investigated components was performed in three replicates. The results were analysed using MATLAB (MathWorks Inc.; Natick, MA, USA) and JMP (Version 7.0; SAS Institute Inc., Cary, NC, USA). Mean differences were tested for significance with a least significant difference test at a 5% level of significance. To describe the thin layer drying characteristics of sliced green table olives, the model with the lowest reduced chi-squared (χ^2) and root mean square error (RMSE) values and the highest coefficient of determination (R^2) was selected (Chayjan *et al.*, 2011; Goyal *et al.*, 2006). These statistical values are defined as the following:

$$\chi^2 = \frac{\sum_{i=1}^N (MR_{\text{exp},i} - MR_{\text{pre},i})^2}{N - n} \quad (6)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (MR_{exp,i} - MR_{pre,i})^2}{N}} \quad (7)$$

Where $MR_{exp,i}$ is the experimental moisture ratio in the test with number i , $MR_{pre,i}$ is the estimated moisture ratio in the test with number i , N is the observation number, and n is the number of constants in the drying model.

3. Results and discussion

Drying kinetics of sliced olives

The drying curves of olive samples dried using different methods is presented in Figure 1. To reach the desired moisture content, analysis of the test results showed that drying lasted for 475 min at 50 °C or for 195 min at 75 °C using convection drying; for 530 min at 90 W microwave power; and for 185 min at 160 W microwave power. For the combined microwave-convective method, the drying of olive samples at 90 W-50 °C, 90 W-75 °C, 160 W-50 °C and 160 W-75 °C lasted 335, 175, 145 and 105 min, respectively. Test results showed that the use of the combined microwave-convective method provided considerable time savings compared to convective or microwave drying alone. Funebo and Ohlsson (1998) and Contreras *et al.* (2008) reported that the combined microwave-convective method significantly reduced drying time for fruits and vegetables. In addition, all tests showed that increased temperature and increased microwave power reduced drying time significantly. These results are similar to those reported by Ongen *et al.* (2005) and Demir *et al.* (2007) for the convective drying of table green olives and by Özbek and Dadalı (2007) and Inchuen *et al.* (2008) for the microwave drying of different food materials.

Variations in the drying rates and time required to desired level of desiccation under different drying conditions are shown in Figure 2. Considering all drying conditions, the olive samples dried by the combined microwave-convective method had a faster drying rate than those samples dried

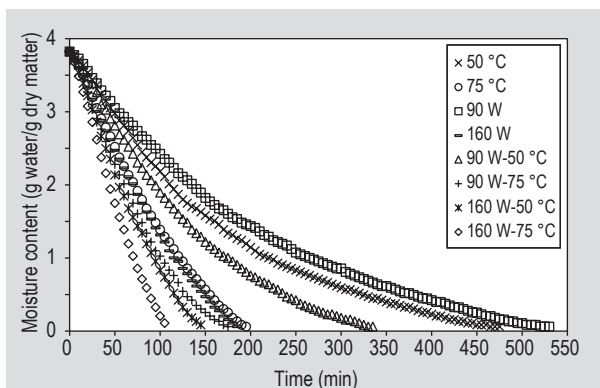


Figure 1. Drying curves of olive samples under different drying conditions.

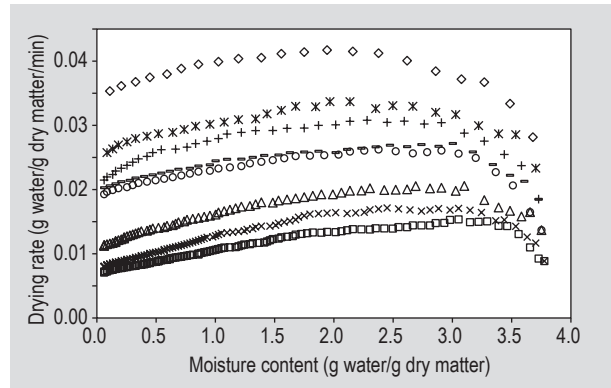


Figure 2. The drying rates of olive samples versus the moisture contents at convective temperatures (50 and 75 °C), microwave power (90 and 160 W) and microwave-convective combinations (90 W-50 °C, 90 W-75 °C, 160 W-50 °C and 160 W-75 °C).

only with microwaves or convection, and thus, faster moisture removal was achieved in these olive samples. Furthermore, as drying temperature and microwave power increased, drying rates increased as well. Similar results were obtained by Doymaz (2007) and Eştürk and Soysal (2010). In general, with the convective drying method the drying rates of foods are slowed down mainly due to the slow effects of heat on the inner sections of products with low moisture content. To overcome this problem, a typical strategy is to combine convection with microwave drying. In products dried with microwaves, the microwave energy easily penetrates the inner sections of the products, and thus, the problems of a lower drying rate and long drying periods are overcome. The most important effect of microwave power in combined systems is that it increases the slow drying rate of hot air (Al-Duri and McIntyre, 1992; Karaaslan and Tuncer, 2008).

Fitting of drying curves

The moisture content data observed at different drying conditions were converted to the more useful the moisture ratio values, and these values were used to analyse the fit of thin layer drying models (Akpinar, 2006). To estimate moisture ratio values, nine different thin layer drying models were used for the different drying methods, and these results are presented in Table 1. Using these models, the drying times and the variation in moisture ratio values found using the convective, microwave and combined microwave-convective drying methods of olive samples were modelled, and the drying coefficients and R^2 , RMSE and χ^2 of these models are presented in Table 2, 3 and 4. Based on these results, the Midilli *et al.* (2002) model was the best of the evaluated models at explaining the variations in moisture ratios found in all tests. In addition, in all cases, the R^2 value of the Midilli *et al.* (2002) model was greater than 0.9992; the RMSE and χ^2 values were smaller than 0.0079 and 0.5179, respectively.

Table 2. Estimated values of coefficients and statistical analyses obtained from various thin layer drying models for drying of olives at different temperatures.

Model no. ¹	50 °C				75 °C			
	Model coefficients	R ²	RMSE	$\chi^2(10^{-4})$	Model coefficients	R ²	RMSE	$\chi^2(10^{-4})$
1	a=1.063; k=0.006586	0.9951	0.0200	3.9257	a=1.113; k=0.01209	0.9706	0.0533	28.0675
2	k=0.006195	0.9909	0.0273	7.3999	k=0.01081	0.9550	0.0660	42.7931
3	k=0.00275; n=1.155	0.9980	0.0128	1.5565	k=0.001434; n=1.441	0.9947	0.0227	5.1872
4	a=1.104; k=0.005485; c=-0.07219	0.9992	0.0082	0.6045	a=1.574; k=0.005588; c=-0.5382	0.9992	0.0090	0.6448
5	a=-8.185; k ₀ =0.009856; b=9.205; k ₁ =0.00932	0.9979	0.0130	1.6047	a=1.145; k ₀ =0.01245; b=-0.1453; k ₁ =5.501	0.9737	0.0504	25.2342
6	a=1.676; k=0.008103	0.9978	0.0135	1.7431	a=0.00007081; k=152.6	0.9537	0.0668	43.9400
7	a=-0.004571; b=0.000005436	0.9922	0.0253	6.2937	a=-0.007614; b=0.00001258	0.9985	0.0121	1.2322
8	a=2.495; k=0.004006; b=0.7482	0.9983	0.0116	1.2903	a=8.108; k=0.004158; b=0.8473	0.9934	0.0253	5.9329
9	a=1.026; k=0.005026; n=1.03; b=-0.0001047	0.9993	0.0078	0.5178	a=1.01; k=0.003568; n=1.184; b=-0.0008233	0.9997	0.0051	0.1588

R² = coefficient of determination; RMSE= root mean square error.
¹Description of the thin layer drying models are given in Table 1.

Table 3. Estimated values of coefficients and statistical analysis obtained from various thin layer drying models for drying of olives at different microwave powers.

Model no. ¹	90 W				160 W			
	Model coefficients	R ²	RMSE	$\chi^2(10^{-4})$	Model coefficients	R ²	RMSE	$\chi^2(10^{-4})$
1	a=1.058; k=0.005516	0.9929	0.0239	5.7525	a=1.108; k=0.01254	0.9688	0.0547	30.3491
2	k=0.005211	0.9892	0.0296	8.7480	k=0.01126	0.9544	0.0662	44.4687
3	k=0.002188; n=1.16	0.9969	0.0158	2.3967	k=0.001504; n=1.443	0.9942	0.0237	5.4692
4	a=1.125; k=0.00428; c=-0.1077	0.9994	0.0068	0.3891	a=1.623; k=0.005512; c=-0.594	0.9992	0.0090	0.7655
5	a=11.6; k ₀ =0.007918; b=-10.58; k ₁ =0.008278	0.9969	0.0160	2.4532	a=1.14; k ₀ =0.01292; b=-0.14; k ₁ =4.192	0.9716	0.0522	27.6866
6	a=1.677; k=0.006829	0.9968	0.0161	2.4779	a=1.939; k=0.01731	0.9903	0.0304	9.2122
7	a=-0.003871; b=0.000003909	0.9942	0.0216	4.4974	a=-0.007913; b=0.0000134	0.9989	0.0103	1.0750
8	a=1.095; k=0.004177; b=-0.08898	0.9991	0.0083	0.5968	a=8.147; k=0.004222; b=0.8423	0.9940	0.0241	6.1173
9	a=1.022; k=0.004794; n=0.9953; b=-0.0001547	0.9995	0.0062	0.3281	a=1.003; k=0.003479; n=1.196; b=-0.0009015	0.9997	0.0053	0.1799

R² = coefficient of determination; RMSE= root mean square error.
¹Description of the thin layer drying models are given in Table 1.

Figure 3 presents the moisture ratio values obtained experimentally from all drying conditions used on olive samples and the variation of estimated moisture ratio

values obtained from the Midilli *et al.* (2002) model in the literature. As shown in Figure 3, the estimated values obtained from the Midilli *et al.* (2002) model and the values

Table 4. Estimated values of coefficients and statistical analysis obtained from various thin layer drying models for drying of olives at different microwave power and temperature combinations.

Model no. ¹	Model coefficients	R ²	RMSE	$\chi^2(10^{-4})$	Model coefficients	R ²	RMSE	$\chi^2(10^{-4})$
90 W-50 °C					90 W-75 °C			
1	a=1.088; k=0.008546	0.9886	0.0318	10.2521	a=1.119; k=0.01463	0.9712	0.0541	29.3783
2	k=0.007857	0.9802	0.0420	17.7330	k=0.01307	0.9555	0.0672	44.8648
3	k=0.002101; n=1.265	0.9980	0.0134	1.8025	k=0.001692; n=1.462	0.9966	0.0186	3.4443
4	a=1.192; k=0.006148; c=-0.1537	0.9991	0.0087	0.6510	a=1.44; k=0.007758; c=-0.3934	0.9977	0.0154	2.2853
5	a=1.104; k ₀ =0.008675; b=-0.1043; k ₁ =10.24	0.9899	0.0300	9.1794	a=26.26; k ₀ =0.003334; b=-25.33; k ₁ =0.003124	0.9770	0.0483	22.9201
6	a=1.813; k=0.01112	0.9973	0.0155	2.4068	a=0.0000743; k=175.9	0.9542	0.0682	46.2052
7	a=-0.005823; b=0.000008718	0.9983	0.0123	1.3668	a=-0.009317; b=0.00002014	0.9974	0.0164	2.4437
8	a=3.912; k=0.007364; b=0.9782	0.9800	0.0421	17.8717	a=1.246; k=0.01293; b=0.9571	0.9529	0.0691	47.5165
9	a=1.011; k=0.003652; n=1.135; b=-0.000188	0.9997	0.0055	0.2087	a=1.001; k=0.00295; n=1.3; b=-0.0005251	0.9996	0.0062	0.2982
160 W-50 °C					160 W-75 °C			
1	a=1.111; k=0.01574	0.9659	0.0581	34.0141	a=1.114; k=0.01995	0.9570	0.0660	44.2492
2	k=0.01409	0.9506	0.0699	49.2492	k=0.01775	0.9403	0.0778	62.2253
3	k=0.001805; n=1.477	0.9946	0.0231	5.3527	k=0.00185; n=1.561	0.9950	0.0226	4.7960
4	a=1.697; k=0.006551; c=-0.6652	0.9986	0.0116	1.2832	a=2.168; k=0.006143; c=-1.136	0.9981	0.0139	1.9808
5	a=37.66; k ₀ =0.02702; b=-36.55; k ₁ =0.02755	0.9796	0.0450	20.2604	a=69.6; k ₀ =0.03193; b=-68.59; k ₁ =0.03226	0.9796	0.0455	21.4846
6	a=1.966; k=0.02201	0.9904	0.0307	9.5667	a=2.01; k=0.0287	0.9890	0.0334	11.1191
7	a=-0.009795; b=0.00001964	0.9981	0.0137	1.8310	a=-0.01189; b=0.00002236	0.9972	0.0169	3.1473
8	a=4.162; k=0.004753; b=0.6085	0.9960	0.0200	4.0765	a=4.639; k=0.008264; b=0.773	0.9756	0.0497	25.8276
9	a=1.002; k=0.003795; n=1.241; b=-0.001089	0.9996	0.0061	0.3185	a=0.9981; k=0.003411; n=1.333; b=-0.001584	0.9998	0.0048	0.1115

R² = coefficient of determination; RMSE= root mean square error.

¹Description of the thin layer drying models are given in Table 1.

obtained experimentally were quite similar. Previous studies reported that the Midilli *et al.* (2002) model was the best to model thin layer drying methods for various products (Akpınar, 2006; McMinn, 2006; Mundada *et al.*, 2010).

Colour analysis

The colour and brightness of a food item are among the most important quality indicators used to assess acceptability of a dried products by customers (Devahastin and Niamnuy, 2010). The colour parameters L*, a*, b*, C and α of fresh and dried olive samples using different

drying methods are presented in Table 5. While the L*, b*, C and α values of dried sliced green olives decreased by 33, 27, 24 and 10%, respectively, the a* value increased by 34%. These decreases and increase in colour were found to be statistically significant ($P \leq 0.05$). Of the three drying methods used, the smallest colour loss was found at the 160 W microwave power, while the greatest colour loss was found with the 75 °C convective drying method. Chlorophyll pigments are responsible for the green colour of olive fruit (Minguez-Mosquera and Gallardo-Guerrero, 1995) and they can be easily degraded by thermal treatment that resulting in colour changes in food (Clydesdale, 1998).

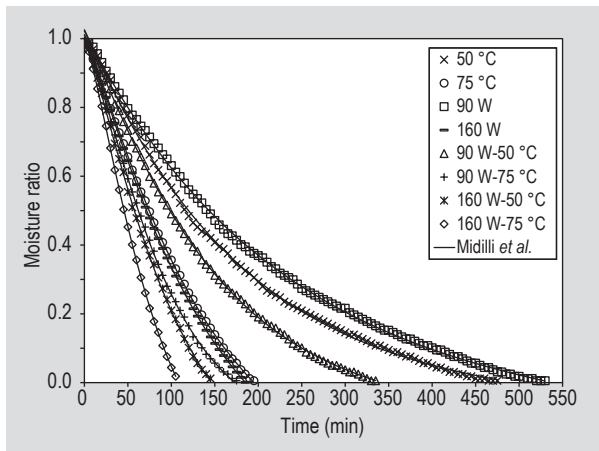


Figure 3. A comparison of the experimental and theoretical moisture ratios predicted by the Midilli *et al.* model at during drying times under all drying conditions.

Colour changes that occur during the drying of fruits and vegetables are caused by enzymatic and non-enzymatic browning reactions (Kammoun *et al.*, 2011). Vadivambal and Jayas (2007) reported that drying treatment increased the a^* value, which indicated that browning reactions were occurring, and that the microwave drying method caused less browning than convective drying. The L^* values of samples dried by the convective and the microwave-convective combined methods were found to be lower than those dried by the microwave method. The fact that among the samples dried with microwave, the best colour values were obtained from the use of 160W microwave power is likely caused by the shorter drying time. Ongen *et al.* (2005) reported that while the L^* and b^* values decreased, the a^* value increased in whole green olives dried with hot air. In

another study, sliced green olives dried with hot air (65 °C) exhibited a decrease in the L^* value from 51.46 to 32.35; and in the b^* value from 31.65 to 17.03; and an increase in the a^* value from 0.62 to 1.95 (Erbay *et al.*, 2010).

The C and α values, which are the colour saturation and colour shade of fresh samples (Wojdylo *et al.*, 2009), were computed as 35.918 and 77.983, respectively. The highest C value was obtained with the 75 °C convective drying, while the lowest α value was obtained with the 160 W-75 °C combined microwave-convective method. These values show decreases of approximately 24 and 10%, respectively. The C and α values of the samples dried with a 160 W microwave were found to be closest to those of fresh sliced green olive samples. It was found that the colour saturation of samples dried under all drying conditions decreased and lost shininess compared to the appearance of fresh samples. Erbay *et al.* (2010) reported that the α value decreased from 89.98 to 55.56 in sliced green olives dried with hot air.

Total phenolic content

The total phenolic contents of fresh and dried samples that were dried with different drying methods are presented in Figure 4. The total phenolic content of fresh sliced green olives was found to be 569.459 mg CA /100 g (d.b.). The total phenolic content of the samples after all drying methods decreased by 74-78% ($P \leq 0.05$). Drying is a procedure that creates varying degrees of negative impacts on food components with antioxidant properties. The decrease in total phenolic content of dried samples could be explained by the degradation of some polyphenols due to drying process didn't immediately inactivate the oxidative enzymes such as polyphenoloxidases and peroxidases (Garau *et al.*,

Table 5. Colour values (\pm standard deviation) of fresh olives and samples dried using different drying methods.

Drying method	Colour parameters				
	L^*	a^*	b^*	C	α^o
Fresh	57.600 \pm 0.036 ^a	7.530 \pm 0.015 ^e	35.120 \pm 0.045 ^a	35.918 \pm 0.047 ^a	77.938 \pm 0.013 ^a
Convective drying					
50 °C	41.090 \pm 0.734 ^{cd}	8.892 \pm 0.674 ^{cd}	28.935 \pm 0.526 ^{bc}	30.300 \pm 0.702 ^{bc}	72.810 \pm 0.924 ^{bc}
75 °C	38.418 \pm 0.870 ^f	8.635 \pm 0.183 ^d	25.777 \pm 0.843 ^f	27.186 \pm 0.809 ^f	71.503 \pm 0.640 ^f
Microwave drying					
90 W	41.627 \pm 0.117 ^c	9.607 \pm 0.657 ^b	27.958 \pm 0.415 ^{de}	29.914 \pm 0.450 ^{de}	71.655 \pm 0.705 ^{ef}
160 W	43.108 \pm 0.131 ^b	8.732 \pm 0.269 ^d	29.147 \pm 0.069 ^b	30.427 \pm 0.058 ^b	73.361 \pm 0.511 ^b
Microwave-convective drying					
90 W-50 °C	40.075 \pm 1.970 ^e	9.062 \pm 0.012 ^{cd}	28.242 \pm 0.394 ^d	29.660 \pm 0.378 ^{cd}	72.245 \pm 0.216 ^{cde}
90 W-75 °C	40.210 \pm 0.876 ^{de}	8.680 \pm 0.368 ^d	27.553 \pm 0.313 ^e	28.889 \pm 0.408 ^e	72.557 \pm 0.516 ^{cd}
160 W-50 °C	41.590 \pm 0.793 ^c	9.260 \pm 0.317 ^{bc}	28.580 \pm 1.392 ^{bcd}	30.046 \pm 1.336 ^{bc}	72.058 \pm 0.950 ^{def}
160 W-75 °C	40.177 \pm 0.069 ^{de}	10.108 \pm 0.126 ^a	28.300 \pm 0.396 ^{cd}	30.052 \pm 0.330 ^{bc}	70.375 \pm 0.483 ^g

^{a-g} Means followed by different superscript letters in the same column differ significantly ($P \leq 0.05$).

2007). The 160 W-75 °C microwave-convective drying resulted in a total phenolic content closest to that of fresh samples, while the 90W microwave method resulted in the greatest difference between dried and fresh sample. This difference may have resulted from the shortest drying time at 160 W-75 °C and the longest drying time at 90 W. Previous studies reported that the total phenolic content decreased with extended drying times (Kwok *et al.*, 2004; Wojdylo *et al.*, 2009). In addition, while there was no significant difference between other convective (50 and 75 °C) and combined microwave-convective methods (90 W-50 °C, 90 W-75 °C, 160 W-50 °C) ($P>0.05$), the 160 W microwave method was found to have significantly higher phenolic values than those treatments ($P\leq 0.05$). Some previous research found that microwave drying gave better results for total phenolic content than convective drying (Arslan and Ozcan, 2010; Igual *et al.*, 2012; Inchuen *et al.*, 2008; Jing *et al.*, 2010). While some of the studies reported that drying resulted in a decrease (Miranda *et al.*, 2010; Sultana *et al.*, 2012; Zanoelo *et al.*, 2006) or increase (Arslan and Ozcan, 2010; Jing *et al.*, 2010; Turkmen *et al.*, 2005) in total phenolic content. For this reason, it can be concluded that the effects of drying treatments on total phenolic content are different with different products.

Antioxidant activity

The antioxidant activities of sliced green olives dried by the convective, microwave and combined microwave-convective methods are presented in Figure 5. As expected, the highest antioxidant activity was found in the fresh sample (48.859%), and this value was significantly different from the values obtained from all drying conditions ($P\leq 0.05$). Among the three drying methods, the highest loss occurred with the 90 W (26.138%) microwave method, while the lowest loss occurred with the 160 W-75 °C

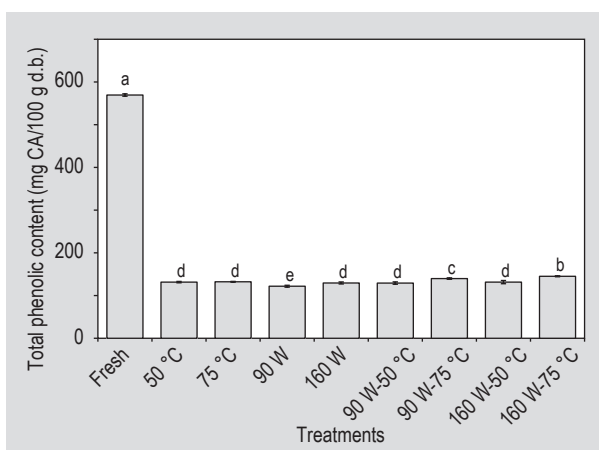


Figure 4. The effects of different drying methods (fresh, 50 °C, 75 °C, 90 W, 160 W, 90 W-50 °C, 90 W-75 °C, 160 W-50 °C and 160 W-75 °C) on total phenolic content of olive samples. Bars with different letters are significantly different ($P\leq 0.05$).

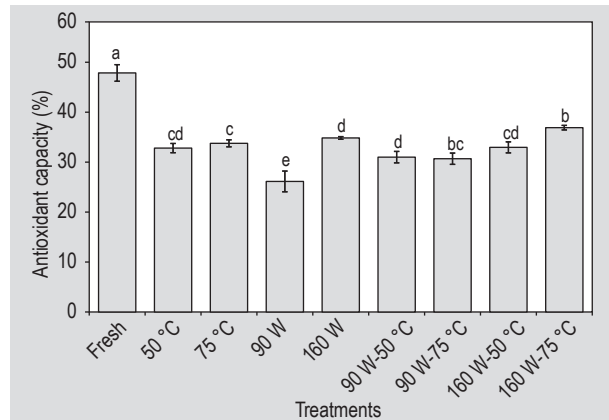


Figure 5. The effects of different drying methods (Fresh, 50 °C, 75 °C, 90 W, 160 W, 90 W-50 °C, 90 W-75 °C, 160 W-50 °C and 160 W-75 °C) on antioxidant capacity of olive samples. Bars with different letters are significantly different ($P\leq 0.05$)

(36.900%) combined microwave-convective method. Furthermore, the antioxidant activities after the 90 W-50 °C and 90 W-75 °C combined microwave-convective drying methods were found to be statistically higher than those after the 90W microwave method ($P\leq 0.05$). This difference may have resulted from reductions in damage to compounds with antioxidant activity from a shorter drying time (Kwok *et al.*, 2004). Based on these results, the combined microwave-convective drying method was found to be more successful at maintaining the antioxidant values of sliced green olives than the microwave drying method alone. Many researchers reported decreased antioxidant activity after drying of food products (Lopez *et al.*, 2010; Sultana *et al.*, 2012; Wojdylo *et al.*, 2009). Phenolic compounds appear to be the main compounds contributing to the antioxidant activities of fruits and vegetables (Karakaya, 2004). Previous research reported that there was a positive relationship between total phenolic content and antioxidant activity (Inchuen *et al.*, 2008; Sultana *et al.*, 2012). Our findings show a positive relationship between total phenolic content and antioxidant activity.

4. Conclusions

This study determined the effects of convective, microwave and combined microwave-convective drying methods on drying characteristics, colour, total phenolic content and antioxidant activity of sliced green table olive. The shortest drying time (105 min) was found in 160 W-75 °C and it was found that combined microwave-convective drying method provided higher time-saving than other methods. Also, the results verified that drying rates were increased with increasing drying temperature and microwave power. Among all applied mathematical models, Midilli *et al.* (2002) model was found to be the best model, which explained test data for sliced green olives samples in all drying conditions. While L^* , b^* , C and α values decreased, a^* value increased in

dried sliced green olive samples. The highest total phenolic content and antioxidant activity was determined in fresh sample. It was concluded that this can be caused by varying degrees of negative impact of drying treatments on nutrition components with antioxidant property.

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